The Comparison of Spectral Top-of-Atmosphere Reflectances Measured by AATSR, MERIS, and SCIAMACHY Onboard ENVISAT

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***Abstract*—The top-of-atmosphere reflectance measurements by Advanced Along-Track Scanning Radiometer (AATSR), Medium-Resolution Imaging Spectrometer (MERIS), and Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) onboard ENVISAT have been compared for collocated scenes. The AATSR and MERIS observations were averaged to the scale of a SCIAMACHY ground scene (30 km $\times$ 60 km). The SCIAMACHY reflectances were averaged to account for much coarser spectral resolution of AATSR and MERIS observations. It was found that SCIAMACHY reflectances coincide with those of MERIS within 4% MERIS calibration error. This is also the case for AATSR reflectances, except at the wavelength of 0.865 μm, where SCIAMACHY gives, on average, 6% lower reflectances as compared to those of AATSR. They are 3% too low as compared to MERIS observations at this wavelength.**

***Index Terms*—Calibration, reflectance, remote sensing, satellite.**

I. INTRODUCTION

THE ENVIRONMENTAL Satellite (ENVISAT) was launched by the European Space Agency more than five years ago (March 1, 2002). It hosts ten scientific instruments with different levels of performance after five years in operation. The Advanced Along-Track Scanning Radiometer (AATSR), Medium-Resolution Imaging Spectrometer (MERIS), and Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) are, so far, in good shape and provide a wealth of information on atmosphere, ocean, and land characteristics. The instruments have different spatial and spectral resolutions and provide complementary information with respect to oceanic, atmospheric, and land processes. The focus of MERIS is on the ocean color. AATSR is aimed to the determination of the sea temperature from space, and SCIAMACHY is the atmospheric chemistry mission instrument aimed to the determination of the concentration of trace gases. The values of spectral reflectances measured by these advanced instruments are used to study atmosphere and underlying ground properties. Therefore, it is of importance to understand how different are the measured reflectances derived from AATSR, MERIS, and SCIAMACHY data for the same scene under the same illumination and observation conditions.

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TABLE I
CHARACTERISTICS OF SELECTED ENVISAT INSTRUMENTS (AROUND 10:00 EQUATOR CROSSING LOCAL TIME)

Instrument	Swath	Channels	Spatial resolution at nadir	Multi-angle observation
MERIS	1150km	15 bands 0.4-1.05 μm (0.41,0.44,0.49,0.51,0.56, 0.62,0.665,0.681,0.705,0.754, 0.76,0.775,0.865,0.89,0.9 μm)	0.3km*0.3km (1.2km*1.2km reduced resolution was used in this paper)	no
AATSR	512km	7 bands 0.55,0.66, 0.87, 1.6, 3.7, 10.85, 12.0 μm	1km*1km	yes, 2 angles from the ranges 0-21.7 and 53-55.6 degrees
SCIAMACHY	916km	hyperspectral measurements in the spectral region 0.24-2.4 μm with the resolution from 0.24 to 1.48nm depending on the particular spectral window (Gottwald et al., 2006)	30km*60km	no

Ideally, they must coincide for all three instruments. However, one can also expect differences due to the degradation of instruments in time, inaccurate calibration, thin ice layers formed on optics, etc.

Operational and scientific processing schemes for all three instruments have been updated, and new more accurate scientific atmospheric, oceanic, and land products have been derived. It is planned that the fully recalibrated SCIAMACHY Processor 6 data will become available in 2008. It is known that SCIAMACHY Processor 5 and lower versions had calibration problems. This was reported by a number of authors [1], [4], [5], [8]. In particular, it was found that SCIAMACHY Processor 5 reflectances were 10%–20% too low depending on the spectral range under study. This prevented, for example, an accurate determination of aerosol optical thickness from SCIAMACHY measurements. All SCIAMACHY data have been reprocessed using Processor 6 to account for reanalysis of prelaunched SCIAMACHY calibration performed by [7].

The accuracy of new SCIMACHY Processor 6 data obtained using the validation data set has been studied by [9], who found that SCIAMACHY and MERIS provide comparable

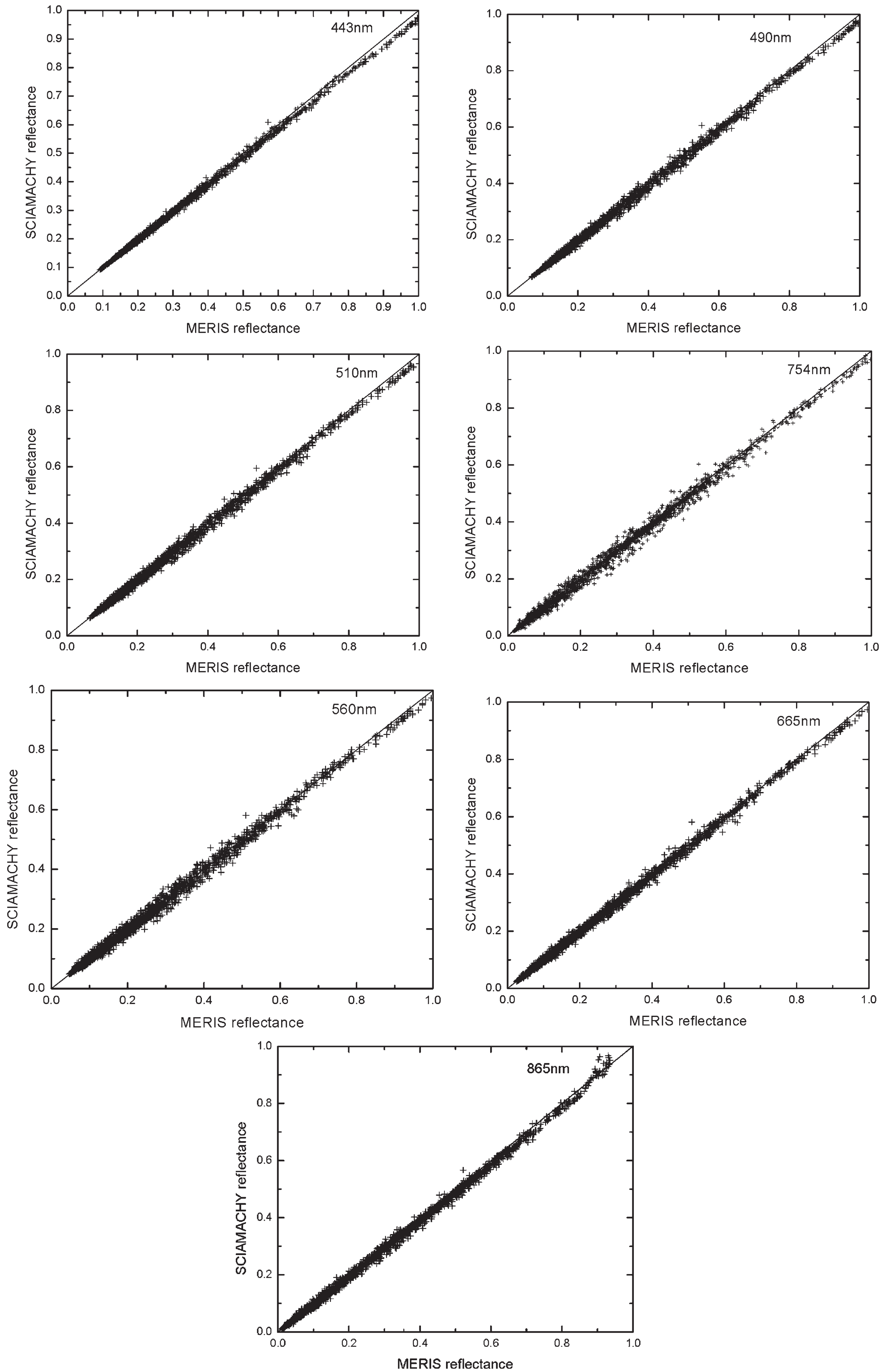

Fig. 1. Intercomparison of MERIS and SCIAMACHY reflectances.

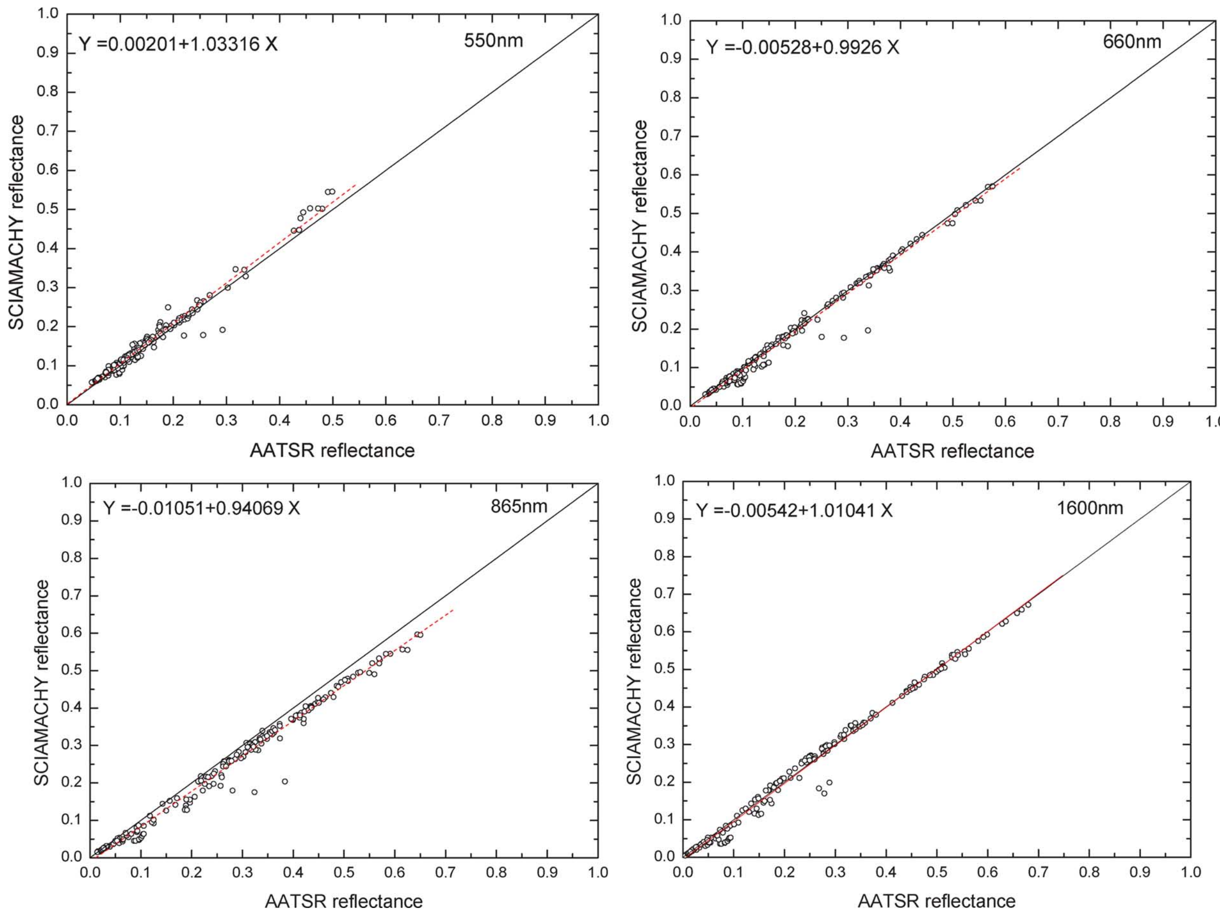

Fig. 2. Intercomparison of AATSR and SCIAMACHY reflectances.

reflectance values in the spectral range of 442–865 nm (within the MERIS 4% calibration error). The aim of this letter is to examine this finding using more extended SCIAMACHY data set (ENVISAT orbit 22321). In addition to MERIS, AATSR data have also been analyzed. This also enabled a comparison for 1600 nm SCIAMACHY channel not available on MERIS.

II. Intercomparison Study

The characteristics of the three instruments used in this letter are given in Table I. MERIS measures top-of-atmosphere reflectance in the spectral range of 0.4–1.05 μm in 15 channels. AATSR in addition to the visible channels have measurements at wavelengths 1.6, 3.7, 10, and 12 μm. SCIAMACHY is the hyperspectral instrument. Its spectral resolution depends on the channel, and it is about 0.4 nm for the channels used in this letter. The measurements are performed in the broad spectral range from 0.24–2.4 μm. Several channels of these instruments almost overlap. They are 0.55 (0.56 μm for MERIS), 0.66 (0.665 μm for MERIS), and 0.865 μm for all three instruments. In addition, both AATSR and SCIAMACHY perform measurements at 1.6 μm. SCIAMACHY hyperspectral measurements have been averaged to the scale of MERIS and AATSR spectral bands using MERIS and AATSR spectral response functions. The temporal mismatch of measurements is negligible, because they are on the same platform. The spatial collocation can be easily done averaging AATSR and MERIS data to the size of SCIAMACHY 30 km $\times$ 60 km pixel [3]. For this, the geographical coordinates of SCIAMACHY pixel corners and also coordinates of MERIS and AATSR pixel centers have been used. The collocation procedure is fully described in a separate publication [10]. This enables the comparison of sun-normalized reflectances

$$R = \frac{\pi I}{\mu_0 F_0} \tag{1}$$

where I is the reflected-light intensity, μ_0 is the cosine of the solar angle, and F_0 is the incident solar flux measured by the diffuser plates present in all three instruments.

The results of comparisons for SCIAMACHY–MERIS and SCIAMACHY–AATSR reflectances are given in Figs. 1 and 2. Data from the ENVISAT orbit 22321 (June 7, 2006) have been used in this letter. First, spectral averaging of SCIAMACHY data was performed. On the second step, the spatial collocation of pixels was performed. The scenes analyzed range from ocean surfaces, which are dark, to bright cloud and snowfields. For the MERIS intercomparison study, 329 SCIAMACHY pixels have been selected (see Fig. 1). For AATSR intercomparison study, 183 SCIAMACHY pixels have been used (see Fig. 2). The swath width of AATSR (512 km) is narrower as compared to MERIS (1150 km). Thus, smaller amount AATSR measurements is available for a single ENVISAT orbit as compared to SCIAMACHY (the swath width is 960 km) and MERIS.

TABLE II
RATIO $R_{\mathrm{scia}}/R_{\mathrm{meris}}$ AND $R_{\mathrm{scia}}/R_{\mathrm{AATSR}}$, RESPECTIVELY, AS DERIVED FROM DATA SHOWN IN FIGS. 1 AND 2 FOR THE SELECTED DATA OF ENVISAT ORBIT 22321 (JUNE 7, 2006)

Wavelength, nm	R_{scia}/R_{meris}	R_{scia}/R_{AATSR}
443	0.9716	-
490	0.9819	-
510	0.9814	-
560	0.9884	1.0332
665	0.9892	0.9926
754	0.9809	-
865	0.9737	0.9407
1600	-	1.0104

It follows from the analysis of figures that SCIAMACHY and MERIS reflectances are very close (within 4% of MERIS calibration error on average) even taking into account very different reflectivity regimes from close to 1.0 (in the visible) reflectances (snow) to those close to 0.05 (ocean). This confirms our earlier studies [9], [10] performed for a single SCIAMACHY state (390 km × 960 km). The ratio $A = R_{\mathrm{scia}}/R_{\mathrm{meris}}$ is very close to one (see Table II). The offset is equal to zero within the accuracy of the intercomparison method used.

It follows that MERIS reflectances are somewhat larger on average as compared to SCIAMACHY reflectances. AATSR reflectances almost coincide with those of SCIAMACHY at 0.66 and 1.6 μm. They are somewhat smaller as compared to collocated SCIAMACHY reflectances at 0.55 μm (3% on average) and about 6% larger on average at 0.865 μm. This also means that AATSR reflectances at 0.865 μm give values larger than those of MERIS on average.

III. CONCLUSION

We draw the following conclusions from this letter. Differences of the top-of atmosphere sun-normalized spectral-reflectance measurements of SCIAMACHY (and also AATSR) from those of MERIS are inside MERIS 4% calibration error [2] in the range of 0.4–0.9 μm. The differences between SCIAMACHY and AATSR values of reflectances reach 6% at 0.865 μm with the underestimation of reflectances by SCIAMACHY. The underestimation of SCIAMACHY reflectances is just 3% as compared to MERIS measurements at the same wavelength. These results are in a much better agreement as compared to SCIAMACHY Processor 5 data, where differences between SCIAMACHY and MERIS/AATSR were above 20% at 0.865 μm [1], [4], [8].

Therefore, we conclude that three ENVISAT instruments considered in this letter measure the top-of-atmosphere reflectance with a similar accuracy. This confirms a good performance of AATSR, MERIS, and SCIAMACHY instruments after five years in operation. This also means that data from these three instruments can be used in exploration of the synergy between different types of measurements provided by these diverse instruments [6].

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